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GEOLOGIC FACTORS IN ORGANIC EVOLUTION.*

KIRTLEY F. MATHER

Department of Geology, Denison University

INTRODUCTION.

The presidential addresses delivered at the last two meetings of our Academy, that by Dr. Weiss† at Oberlin in 1923, and that by Prof. Osburn‡ in this room in 1922, both dealt with phases of the broad principle of organic evolution. It is my purpose this evening to accept the precedent thus established and speak to you from the point of view of the geologist with reference to certain problems of life development. With an audience including specialists in many scientific departments, an occasion of this sort demands the consideration of general principles or problems in which men of varied scientific interests may unite on common ground. No excuse is needed at the present time for offering the manifold enigma of life development as one of the most important fields now being cultivated by men of science. We approach the subject from many angles, but we inevitably find a common interest there.

Geologic factors in their broadest interpretation would, of course, embrace all the elements which compose the physical environment surrounding life at any time or place. Moreover, it is evident that many elements of an animal or plant association are present as a part of the organic environment solely by permission of geographical conditions. So closely interwoven are the two parts of any environment, the physical surroundings

* Retiring President's Address before the Ohio Academy of Science, April 18, 1924.

† A. P. Weiss, The Aims of Social Evolution; Ohio Journal of Science, Vol. 23, pp. 115–134, 1923.

‡ R. C. Osburn, Some Common Misconceptions of Evolution; Ohio Journal of Science, Vol. 22, pp. 173–192, 1922.

and the associated life, that the influence of the one is scarcely separable from the influence of the other and both alike may be considered as geologic factors. My topic, therefore, might be interpreted as involving a consideration of the role played by environment in the processes of evolution.

How environment operates in influencing successive generations in the evolution process is a moot question, perhaps one of the most important of all the unsolved problems with which we are now engaged. The wise student of evolution is today not nearly so dogmatic in his assertion that acquired characteristics are not inheritable as were many naturalists a few years ago. Most paleontologists have harboured a lingering hope that in some way the characteristics acquired by one generation may leave their impress upon the next generation. The record of the rocks frequently suggests the question, does environment influence the germ plasm and therefore have something to say about the nature of those born into each generation? Or does environment merely select from those born the few who are to survive because of chance adaptation to their surroundings? Although the geologic record inevitably raises that question, it is probable that no certain answer can be deduced from the study of geologic life development. The problem cannot be solved by the paleontologist because what he sees can be rationally explained on either basis. Apparently the solution must await the results of such studies as are now being prosecuted by experimenting biometricians.

Even though the paleontologist must give over the hope of finding the elusive answer to such fundamental questions as these, it is of real value for him occasionally to take stock of his information and to survey the stage upon which the drama of life has been played. The shift of scenes and change of properties has always found quick response from the actors in the play. A review of such responses at certain critical moments in the past, coupled with an attempt to explain them, may help us as we chart the course which mankind may hope to pursue through coming geologic epochs.

GEOLOGIC FACTORS IN THE ORIGIN OF LIFE.

The first appearance of living organisms upon the earth constitutes an event which will always be fraught with the profoundest interest, but which will probably ever be shrouded in deep mystery. Almost altogether unhampered by facts, one is left free to speculate along many different avenues. Geologists and astronomers seem in general agreement concerning the likelihood that our earth has passed through a juvenile stage of growth by accretion of "planet dust." The Planetesimal Hypothesis of Chamberlin and Moulton, or some modification of that hypothesis, makes a strong appeal to all who have attempted to sketch the evolution of the solar system. Long before the earth had attained its present maturity, its surface conditions would presumably have been favorable for life as we know it today. All available data indicate that ever since the earth was of dimensions comparable to those now possessed by Venus its atmospheric constitution, surface temperatures, light intensity, etc. have been within the range of conditions under which life is known to exist.

It would be expected that no long delay would ensue after the earth became suitable as an abode for life before that opportunity would have been seized and life originated. If such was the case, living creatures have existed on the earth from a date which must be placed far back beyond the dawn of geologic history, long before the oldest known rocks were formed. The surface of the juvenile earth of that early time must now be buried hundreds of miles deep beneath the materials subsequently added to it during the final stages of organization of the solar system. The high temperature and intense pressure of the earth's interior have long since completely altered those ancient surficial rocks beyond any possibility of recognition. The vast eon of time which has since elapsed has effectively obliterated all vestiges not only of the primordial life itself, but of its terrestrial environment as well.

The only safe grounds within which speculation concerning the origin of life is justified are those which imply that the material substances from which living cells were first constructed were previously present among the rocks and minerals of the earth. Frost,* Osborn†, and others have stressed the fact that the chemical elements essential in living protoplasm

* E. B. Frost, The Contribution of Astronomy to General Culture; Journ. Sci. Lab. Denison Univ., Vol. 16, p. 360, 1911.

† H. F. Osborn, The Origin and Evolution of Life, New York, 1918, pp. 45-48, 59-67.

are among the most ubiquitous of all the elements in the universe. All the necessary ingredients were certainly present in the outer shell of the growing earth. The geologic factors involved in the accretion of planetesimal matter upon the earth's surface afforded almost limitless variety of chemical combinations. The Chamberlins,* father and son, have called our attention to the many unstable and highly complex carbides, nitrides, phosphides, etc., present in the meteorites which have reached the earth's surface during recent time. Presumably these are samples of the material added to the juvenile earth during its Formative Eon. Chamberlin† has set forth in a characteristic masterpiece of logical deduction many reasons for the belief that the pulverized and porous surface layer of the growing earth was the most probable environment in which life may have originated. The open spaces at variable depths below the actual surface of the lithosphere must have been filled by the water of the primitive hydrosphere. Except during times of precipitation, the pores in the ground in close proximity to the surface were comparatively dry. Somewhere between the water table and the surface any desired relationship of water, air, and mineral matter could have been found. Here the long, slow process of chemical synthesis, constructing the chain which led eventually to the first protoplasm, is believed to have taken place. Beyond doubt, there were numerous errors in the many trials attempted at different times and places, but opportunity was practically limitless both in time and space. If the requisite minerals were wanting at a critical point in the synthetic processes in one place, somewhere else the proper sequence might be obtained. If at one locality an unfortunate episode of volcanic activity, crustal movement, or planetesimal infall destroyed the delicate balance between the complex hydrocarbon compounds and their surroundings, somewhere else at some other time there would be no such untoward circumstances.

Chamberlin‡ and Osborn§ have both commented on the frequency with which complex hydrocarbon compounds assume the colloidal rather than the crystalline state. It is thus that

* T. C. Chamberlin and R. T. Chamberlin, Early Terrestrial Conditions that may have Favored Organic Synthesis; Science, Vol. 28, pp. 902-904, 1908.

† T. C. Chamberlin, The Origin of the Earth, Chicago, 1916, pp. 252–256.

‡ Loc. cit., pp. 255–257.

§ Loc. cit., pp. 58–59.

the inorganic world simulates i its physical appearance and constitution the organic. More than likely the postulated chemical synthesis was favored by the presence of colloids in the interstices between the grains of the outer shell of that primitive earth. The suggestion has been made that the walls bounding the tiny spaces in the soil anticipated the development of cell walls inclosing the protoplasm of the primitive unicellular plant-animal.

But this is only a part of the story. Life is something more than matter. Living creatures are characterized by vital energy; something about which we really know very little, but something which is absolutely indispensable to every organism. Obviously the material constituents of life were under the sway of geologic factors. Did those same factors also determine the energy content of the ancestral cell? Abundant sources of energy of various kinds were doubtless present at and near the surface of the growing earth. Solar radiance, electrical vibrations, radioactive compounds, chemical reactions, all of these and perhaps other sources of energy were available. It is conceivable that the synthesis of vital energy paralleled in the spiritual realm, if I may use that term in a very broad sense, the synthesis of protoplasmic substance in the material realm. Here the geologic factors are so obscure that it is hardly worth while to attempt any speculation.

Chamberlin* closes his volume on the origin of the earth with the following thought-provoking sentence: "It is our personal view that what we conveniently regard as merely material is at the same time spiritual, that what we try to reduce to the mechanistic is at the same time volitional, but whether this be so or not, the emergence of what we call the living from the inorganic, and the emergence of what we call the psychic from the physiologic, were at once the transcendent and the transcendental features of the earth's evolution." With this conclusion, many geologists are in hearty accord. May it not be that life as we know it is but one manifestation of the mysterious spiritual powers which permeate the universe? The geologic factors assembled in the primitive earth provided an environment within which the spiritual could manifest itself in the material. The form which it should assume may have

* Loc. cit., pp. 261–262.

been largely determined by that environment. At the very genesis of organic evolution the physical environment presented an opportunity and suggested a method for its utilization. The primitive cell was the result.

GEOLOGIC FACTORS IN THE EVOLUTION OF MARINE INVERTEBRATES.

It is a far cry from that hypothetical first cell, the original primitive plant-animal, to the splendid array of widely deployed marine invertebrates which are recorded in the rocks of the Cambrian period. The record of that tremendous transition is almost entirely lost. The rocks of Archeozoic and Proterozoic age, the first two great eras of known geologic time, can scarcely be expected to reveal the secrets which we would like to know. But the succeeding Paleozoic era witnessed what seems to have been the greatest progress and most significant achievements of marine invertebrates. Dynasties like the trilobites reached their climax and declined almost or quite to disappearance. Organic mechanisms peculiarly devised for efficient locomotion were perfected by a vast multitude of diverse creatures. Sense organs of great usefulness were consummated by the representatives of numerous invertebrate orders. Protective devices of shell covering or other structures reached a superiority which has never been excelled. At the close of the era the assemblage of marine invertebrates was far superior in every way to the ancestral types who had embarked upon the Cambrian seas. Were there factors in the Paleozoic environment which could have been responsible for that remarkable progress?

It happens that our knowledge of Paleozoic geography and history is unusually complete. During that long interval of time the eastern half of North America was close to sea level. Successive oscillations of level from time to time changed the relations between land and sea so that great shallow embayments crept inward from the margins of the continent, inundated vast areas in what are now the eastern states, and later withdrew to the very margins of the continental platform. Schuchert in his Paleogeography of North America* has assembled data concerning the displacements of the ocean

* C. Schuchert, Paleogeography of North America; Bull. Geol. Soc. America, Vol. 20, pp. 427-606, 1910.

strand line during the Paleozoic Era. His quantitative estimates of the inundated areas of North America during successive episodes of marine transgression and continental emergence are, of course, only approximations to the actual facts. The data are by no means accurate and such figures must be held subject to considerable change with increased knowledge. Nevertheless, they give a good idea of the areas involved.

The first inundation of our continent at the opening of the Paleozoic Era apparently did not exceed eighteen per cent of the continental area. It was followed by an emergence during which nearly all of the previously submerged area was above sea level. Shortly thereafter a greater transgression of the sea flooded about thirty-one per cent of the continent, and was followed by an emergence in which more than half of the inundated area became dry land. A quantitative estimate of the succeeding oscillations of land and sea may be succinctly given by quoting the figures for each of the stages which Schuchert has reported on his paleogeographic maps. The successive areas of inundation are as follows: 21%, 12%, 23%, 12%, 57%, 10%, 40%, 5%, 35%, 5%, 35%, 20%, 25%, 5%, 13%, 7%, 27%, 3%, and 1% of the present land area. Apparently these oscillations of the shallow continental seas were among the most important factors contributing to the evolutionary processes. The differences in the figures give a fairly accurate impression of the differences in area available for shallow water life. Times of sea advance and marine transgression were characterized by what has frequently been called expansional evolution. The area available for life was constantly increasing; food supplies were abundant; competition was not severe. Marine invertebrates deployed with utter abandon; every possible experiment was tried; new varieties and species appeared, almost without number. Times of continental emergence were marked by restrictional evolution. The area available was constantly diminishing; living creatures were crowded into ever closer proximity one with another; food supplies were more and more insufficient. The struggle for existence became more acute; the many experiments which had been tried during the luxurious ease of the advancing seas were now appraised and tested. Not only were the decidedly unfit creatures blotted out of existence, but in very truth only the fittest survived. The oscillations of the strand line occasioned pulsations of life. Episodes of expansional and restrictional evolution succeeded one another with monotonous regularity.

Another geologic factor worked in close harmony with the changing area of the shallow sea. Advancing seas invaded each continent from several points of the compass contemporaneously. Embayments like Hudson Bay and the Baltic Sea crept in toward the center of the land areas. For long intervals these embayments were more or less completely isolated one from another. In the main, the Paleozoic seas were probably fairly uniform in temperature, but probably differed materially in salinity and turbidity. A particular embayment, therefore, might be hospitable to certain species such as are found among the molluscs, but at the same time inhospitable to other animals like the corals or the crinoids. Isthmian or other barriers from time to time may have effectively prevented the invasion of an embayment by many forms of life inherently suited to its conditions, and thus have isolated its local population from foreign immigration. For these and other reasons, provincial faunas characterized many Paleozoic epochs.

Each province had its own assemblage of plants and animals, set in a physical environment more or less peculiar to itself. In an attempt to cope with its own special problems, each phylum would perfect its own adaptations. Equilibrium within the province would be attained. Creatures favorably adapted to the local situation would develop. Continued transgression upon the land at many times resulted in the coalescence of hitherto isolated seas. An embayment from the Mackenzie valley, extending southward across Iowa into Illinois, might there become confluent with an embayment from the Gulf of Mexico, extending northward across Mississippi and Tennessee and reaching likewise into Illinois. As a rule, at the climax of sea transgression there was much commingling of the waters of previously separated gulfs and bays. The result is obvious. Provincial faunas mingled with each other and invaded territories from which they had earlier been barred. Life quickly assumed a cosmopolitan aspect as the old barriers were broken down. Again there was abundant opportunity for appraisal of results. Experiments which had proved successful in one embayment were now compared with the best that had been achieved in another province. The creatures selected in the earlier elimination trials were now pitted against each other in the championship meet. The cosmopolitan type would be characterized by the best possible selections from the many provincial units.

This shifting emphasis from provincial to cosmopolitan faunas must frequently have coincided with the change from expansional to restrictional evolution. The two factors were closely allied. Together they must have contributed tremendously to the sifting processes. The earlier part of an ideal period of the Paleozoic Era would be marked by slowly advancing seas and expansional evolution. The middle of such a period would witness the climax of expansional development and the mingling of provincial faunas to provide the cosmopolitan type. During the later part of the period, retreating seas would carry toward the continental margins the dwindling remnants of the cosmopolitan faunas. These were times *par excellence* of testing and appraisal. Such pulsations as these in environment and life seem to have provided both the necessity and the opportunity for progressive development among marine invertebrates.

The case is particularly clear for animals of that type in the Paleozoic seas, but it is apparent that similar geologic factors have contributed toward the progress of many organisms at all times. Nature thus provides opportunity for the "ceaseless urge" within the organism to experiment with all possible methods of achieving success. Then come the times of testing, when the results of these numerous experiments are weighed in the balance, one against the other. Here is one of the most significant contributions which geologic factors have made to organic evolution.

GEOLOGIC FACTORS IN THE EVOLUTION OF FISHES.

The first known record of vertebrate life is contained in rocks formed during the second period of the Paleozoic Era. The record is a fragmentary one, but it indicates creatures ordinarily interpreted as primitive fish-like forms. The relics are, however, so obscure that they do not give much of a clew to the solution of the problem concerning the origin of vertebrates. In the present inquiry, however, we are not concerned with the missing link between the first vertebrates and their invertebrate ancestors. Rather we are interested in the environment which favored the development of the higher type of life. Chamberlin* has again given us the advantage of his clear perception of the factors involved. He calls attention to the characteristic distinction between the body form of fishes and that of most other aquatic creatures. He suggests that it is this body form, presumably devised in response to a particular environment, which is the real achievement of these most lowly vertebrates.

To summarize his conclusions, it may be stated that the geologic record contains strong implications that fishes did not originate in the sea. The fragmentary record above referred to is contained in rocks which have been interpreted by many observers as deltaic in nature. The fragments of fish teeth, plates, and bones embedded in the muds and silts, presumably had been transported down a river and thus suffered considerable attrition before they came to rest. The first record of marine fishes, occurring near the close of the next succeeding geological period, decisively indicates long antecedent evolution to account for the wide deployment into diverse orders which had already been accomplished. The complete absence of all ancestral types from the richly fossiliferous marine strata of the earlier Paleozoic periods may be explained only in two ways. Either fishes had been developed in the waters of the land or in some remote and at present altogether unknown sea. Most paleontologists incline to the former view.

"There is only one conspicuous type that is facilely suited to free life, independent of the bottom, in swift streams, and that is the fish-form. The form and the motion of the typical fish are a close imitation of the form and motion of wisps of water-grass passively shaped and gracefully waved by the pulsations of the current. The rhythmical undulations of the lamprey which perhaps best illustrates the primitive vertebrate form, and is itself archaic in structure, are an almost perfect embodiment in the active voice of the passive undulations of river confervæ. The movement of the fish is produced by alternate rhythmical contractions of the side muscles, by which the pressure of the fish's body is brought to bear in successive waves against the water of the incurved sections. In the

* T. C. Chamberlin, On the Habitat of the Early Vertebrates; Journ. Geology, Vol. 8, pp. 400–412, 1900.

movement of a rope of vegetation in a pulsating current, it is the pressure of the pulses of water against the sides of the rope that give the incurvations. The two phenomena are natural reciprocals in the active and passive voices.

"The development in the fish of a rhythmical system of motion responsive to the rhythm impressed upon it by its persistent environment and duly adjusted to it in pulse and force, is a natural mode of neutralizing the current force and securing stability of position or motion against the current, as desired. Beyond question, the form and movement of the typical fish are admirably adapted to motion in static water and that has been thought a sufficient reason for the evolution of the form, and so possibly it may be, but fishes in static water have not as extreme lateral flexibility as have those of running water."*

This very logical explanation of the development of fishes as a response to the environment afforded in swift-flowing streams is of course quite hypothetical. In the present state of knowledge, we have no data adequate either to prove or disprove the theory. It nevertheless opens up a stimulating trend of thought and is in harmonious alignment with deductions made at various other strategic points in life development. Apparently, here as elsewhere, the geologic factors not only set a problem for life to solve, but also whispered a suggestion as to the method of solution.

GEOLOGIC FACTORS IN THE RISE OF TERRESTRIAL VERTEBRATES.

The emergence of air-breathing quadrupeds from the aquatic environment in which live the gill-breathing and finned fishes constitutes one of the most dramatic events along the road leading toward man. Apparently that event occurred shortly after the middle of the Paleozoic Era, for in the later Paleozoic rocks there are abundant footprints and frequent skeletons which indicate the presence of amphibians and reptiles.

Barrell has made a critical study of the geologic factors involved in this particular episode of organic evolution. From his own summary of his paper,† entitled "The Influence of

* T. C. Chamberlin, loc. cit., pp. 407–8.
† J. Barrell, Bull. Geol. Soc. America, Vol. 27, pp. 387–436, 1916.

Silurian-Devonian Climates on the Rise of Air-breathing Vertebrates," the following paragraphs may be quoted.

"The amphibians are represented in the later Paleozoic by certain skeletons preserved in the accumulations of coal swamps, but more abundantly by footprints in formations having the character of semi-arid flood plain deposits. As the record is traced backward, the skeletons disappear, and the oldest abundant traces are footprints left in shales and sandstones, chiefly red in color, of Lower Carboniferous age. These are the deposits of rivers which were in the main subject to seasonal shrinkage in markedly semi-arid climates. The footprints lead us back to the habitats of river fishes, the ancestors from whom they sprang. There are here converging lines of evidence that the rise of amphibians came not from the sea, but from the land waters. The exposure of the tidal zone alternately to water and to air had, then, nothing to do with the origin of lungs.

"Having made this study of environments, the argument passes on to an analysis of causes leading to the rise of amphibians. The law of probabilities shows that the directive influence of external factors is necessary to guide the development of old organic structures into combinations of new structures which shall be efficient under a combination of new conditions. Natural selection, although not now regarded as an explanation of most minor organic variations and the development of new species, is nevertheless a broad controlling force which compels development within certain limits of efficiency. What, then, were the causes which controlled the passage of fishes into amphibians? The chief cause is found to have been the nature of Silurian and Devonian climates. The warm and stagnant waters of the dry season compelled those fishes which should survive to make larger and larger use of air. The organic nature of fishes was at that time happily able to vary in pace with the demands of changing environment.

"The evidence is regarded as strong that the air-bladder was originally developed as a supplemental breathing organ, although in modern fishes it has been mostly diverted to other uses. Among certain Devonian fishes, living under more and more strenuous climatic conditions of seasonal dryness, the use of the air-bladder for respiration became essential, and with the diminishing availability of the waters of certain regions the gills in those species which survived this crisis in evolution became correspondingly atrophied. The amphibians thus arose under the compulsion of seasonal dryness.

"In conclusion, it is noted how the particular method of accessory respiration which was adopted by the ancestors of amphibians was only one of several methods which have been used by fishes. This method of accessory respiration permitted the rise of land vertebrates and determined the future lines of evolution, but another choice of the mode of respiration might have led to more rapid progress—a progress which would, however, have been directed into somewhat different lines."

Barrell thus concludes that "climatic oscillation is a major ulterior factor in evolution." Again, a geologic factor may be observed to play an important directive part in the drama of life development. The necessities imposed upon the organism because of certain peculiarities in the environment formed a problem which was not impossible of solution. The upward step involved in the evolution of amphibians from fishes was occasioned by local and temporary geologic factors. No ultimate goal could possibly have been even fleetingly envisioned by ambitious fishes. To be sure, the successful achievement of air-breathing apparatus permitted later generations of creatures to progress far by numerous subsequent steps, but the future possibilities were not in the least involved in the momentary crisis. Creatures inherently possessing qualifications which made possible the development of primitive lungs were for the moment set in an environment which stimulated that achievement. The result was of far-reaching consequence to all life.

GEOLOGIC FACTORS IN THE ADVENT OF REPTILES.

The outstanding biologic event of the closing Paleozoic periods was the improvement of terrestrial vertebrates until the reptilian stage was reached. The fossil record shows a nearly complete transition between certain amphibians and the more lowly reptilian orders. No such pronounced structural differences as now separate these two classes of vertebrates were present in late Paleozoic time. In its simplest statement, this forward step in life development involved two changes, both of which were necessary to liberate land animals from the necessity of retaining close contact with their ancestral aquatic environment. In the first place, the individual's metamorphosis from the gill-breathing to the lung-breathing stage must take place sufficiently early in the life history of the creature to be complete by the moment of birth. Otherwise, the young must be hatched in the water. In the second place, the egg must be so constructed as to permit its incubation in the air rather than in the water.

Lull* has interpreted these changes as a response to a climate becoming progressively more and more arid. He suggests "that whereas semi-aridity with seasonally recurring rains impelled amphibian evolution, true aridity with undependable rains making amphibian economy impossible stimulated the evolution of the reptiles." This explanation is in perfect harmony with the known facts concerning the extension of wide desert areas in what are now the southwestern states, at a time which is approximately contemporaneous with the first records of true reptiles. It happens that some of the very oldest reptile remains are found in the Coal Measures of Illinois, in strata whose composition clearly indicates the presence of marshes and swamps of so vast dimensions as to have been possible only in a humid region. These were, however, coincident in time with vast arid deserts at no remote distance toward the south and west, and it might well be expected that the early reptiles soon sent expeditionary forces from their birthplace in the desert to the adjacent humid lands with their greater wealth of food resources.

Case† has made a paleogeographic study of the environment of North American vertebrates in the Late Paleozoic. He concludes from the available data that the development of vertebrate life at that time "emphasizes the changes from a long period of slow evolution in a singularly monotonous environment through a period of rapid expansion in a diversified environment" resulting in the final extinction of most of the life strains involved. "The chief directing influence in the sudden expansion was a decided climatic change, accompanied by physiographic changes, induced by an alteration in the level of the surface of the continent." The Pennsylvanian period was the next to the last in the Paleozoic Era and was

* R. S. Lull, Organic Evolution, New York, 1917, pp. 494, 5.

† E. C. Case, The Environment of Vertebrate Life in the Late Paleozoic in North America, Carnegie Inst., Washington, D. C., pub. 283, 1919.

succeeded by the Permian period. During Early Pennsylvanian time, the geologic factors surrounding North American life were singularly uniform over most of the continent. Apparently there was an equably humid climate; great areas of the continent were approximately at sea level, so that wide marshes and swamps were an almost constant feature of the landscape. The ultimate food supply, vegetation, was abundant in quantity and an enormous number of animals must have found easy subsistence. The air-breathing vertebrates were still in the first stage of their development—the stage of youth, with all its resiliency, flexibility, and readiness to experiment. But amphibian development seems to have been especially slow. Case suggests that the monotony of the environment restricted the progress which might otherwise have been expected. The vertebrate fauna was, however, "accumulating force towards a great radiation to be expressed as soon as the limitations were removed even in a partial degree." This was apparently one of several long periods of stagnation in evolution which were followed by rapid development, an association so frequently noted that Case records his "impression that faunas in periods of stagnation go through a period of preparation in some form for their subsequent radiation."

Toward the end of the Pennsylvanian period, far-reaching physical changes began to make themselves apparent throughout North America. In general, there was a gradual elevation of the land, accompanied by changes to a cooler and less humid climate. Swamps and marshes dwindled to disappearance. Wide sandy wastes extended over large areas in both the eastern and western half of the continent. Red beds appear among the upper strata of the Coal Measures, and throughout Permian time rocks of that nature were the dominant type in most parts of North America. "The fauna, long restrained from any expression of its evolutionary tendencies, full-fed and in the vigor of its youth, responded at once to the change, and new forms appeared so suddenly as to be unheralded in the preserved remains." Reptiles made their appearance in considerable force and promptly took command of the available lands. Their deployment into diverse strains was especially rapid and was no doubt a response to the varied opportunities of the notably diversified environment. The strange and mysterious fin-backed lizards, the graceful, slender, swift-moving *Areoscelis*, and the efficiently aquatic mesosaurs are suggestive of the products of three of the many lines of evolution which were pursued.

Somewhat similar climatic and physiographic conditions maintained in South Africa at that same period in earth history. There, also, the reptiles took advantage of the congenial surroundings and the new opportunities. Progress was along very similar lines. But at that locality, one reptile strain showed tendencies which foreshadow the evolution of mammals. So far as the fossil record goes, these tendencies are most apparent in the teeth and skulls. We know nothing definite concerning the progress toward the two truly mammalian characteristics, the utilizing of a portion of the energy derived from food to keep the body temperature above that of the surroundings, and the development of mammary glands for suckling the young. It is, however, within the bounds of probability that both of these mammalian characters were anticipated among therapsid reptiles at that time. If so, it was doubtless a response to another climatic change and thus indicates anew the controlling and directing influence of geologic factors.

The progressive diversification of climate during late Paleozoic time reached its climax with the arrival of a great ice age. In fact, the available evidence would indicate that the late Paleozoic glaciation marked *the* great ice age, for its glaciers were considerably more extensive than those of the much more recent glacial episodes which we commonly designate by that proud term. Regardless of comparisons, during this time of early evolution among the reptiles, there were repeated refrigerations of climate which caused ice sheets to invade the margins of the tropical zone in Africa, South America, and possibly elsewhere. It was at this time that mammal-like characters make their appearance among certain of the reptiles. It was shortly thereafter that the first creatures ordinarily interpreted as mammals left their scanty record in the rocks.

Obviously, diversification of climate, aridity here, glaciation there, are recurrent episodes in the later history of the earth. The opportunity which such climatic factors give for progressive development among land creatures has been offered many times, but only at this critical stage in the evolution of life were there amphibians capable of responding to the growing aridity and thus of developing into reptiles. Only at this time were there primitive reptiles buoyantly youthful, capable of responding to the adversity of progressive refrigeration by developing mechanism for the manufacture and storage of heat within their bodies.

GEOLOGIC FACTORS IN THE RISE OF MAMMALS.

The Mesozoic Era, which followed the Paleozoic, is designated as the "Age of Reptiles" because during that long interval of time, reptiles dominated land, sea, and air. The excellent start which reptiles had made in response to the changing conditions during the closing moments of the Paleozoic Era bore rich fruit in the host of saurians, peculiarly adapted to every conceivable environment, which retained chief prominence throughout Mesozoic time.

But this era is also characterized by the advent and early development of mammals. Fragmentary remains of teeth and jaws, preserved in the rocks formed during the first of the Mesozoic periods, are ordinarily interpreted as indicating the presence of egg-laying mammals of small size and in few numbers. They are beyond doubt the offspring of the therapsid reptiles whose response to the increasing cold of the late Paleozoic glacial epoch foreshadowed mammalian characteristics and blazed the trail for mammalian progress. Although there were considerable fluctuations of climatic and physiographic conditions during Mesozoic time, there were no geographic changes comparable to those which marked the transition from the Paleozoic to the Mesozoic until a somewhat similar transition occurred at the close of the Mesozoic Era. The main lines of evolutionary progress among vertebrates seem to have been blocked out at the very start of Mesozoic time, and were followed with little deviation during its successive periods. The mammals showed a remarkably slow though steady development.

Not a single complete mammal skull, much less a complete mammal skeleton, has yet been secured from Mesozoic rocks. Our information concerning the early progress of mammals is based on fragments of jaws and scattered teeth. These are ordinarily interpreted to mean that about the middle of the era, mammals similar to the marsupials of today were present. These creatures, though viviperous, possess no mechanism for the long continued nourishment of the embryo within the body of the female. Therefore, the young are born in an extremely immature stage and are for a time carried in a pouch on the abdomen of the female. No relics which can possibly be interpreted as pertaining to placental mammals have yet been found in Mesozoic rocks. The peculiarly archaic appearance of the placentals, whose remains are abundant in the first strata of the next era, accords with the customary conclusion that placental mammals did not appear until the transition between Mesozoic and Cenozoic time.

The reasons for this apparent mammalian reluctance to develop rapidly are quite obscure. In part, their stagnation may be explained as similar to that displayed by the amphibians in the latter part of the Paleozoic Era. Mesozoic climates and geography were not nearly so uniform or static as those of early Pennsylvanian time, but on the other hand they were not nearly so varied and diversified as those which characterize the opening and closing epochs of many eras. Again, the slow progress of mammals has been explained as due to the tremendous overburden of reptilian life which temporarily dominated all vertebrate evolution. In the face of such tremendous odds, the mammals could try no new experiments and may have been quite content with their good fortune in managing to escape complete extinction. Yet, this adverse organic environment would seem a likely stimulus toward progress. What achievements were attained by Mesozoic mammals appear in large part a response to the necessities imposed upon them by their reptilian enemies. Such a typically mammalian characteristic as parental affection must have been stimulated by the necessity of protecting immature young from the depredations of the multitude of carnivorous dinosaurs and other blood-thirsty saurians. Mammalian intelligence, whether instinctive or reasoning, may likewise have been stimulated in a similar way. Frail and puny mammals could escape powerful and huge reptiles only by outwitting their more muscular opponents. Sharp wits rather than sharp claws, quickness of mind rather than quickness of limb, stood the mammals in good stead in those dark ages of reptile strength.

Attention has frequently been called to the fact that the customary food of placental mammals is directly or indirectly supplied by angiospermous vegetation. Nuts and fruits, herbs and grains, grasses and shrubs, are the basic food resources of all modern animals. None of these were present in any abundance at the opening of Mesozoic time. Although scanty records of plants believed to be primitive angiosperms have recently been found in the late Paleozoic Coal Measures, it is certainly true that angiosperms were not present as a quantitatively important part of the flora until after the middle of the Mesozoic Era. The revolution in the flora which took place at that time did not, however, make any great impress upon terrestrial life. It is hardly possible that the lands upon which angiosperms became numerous were geographically isolated from those upon which the Mesozoic mammals were residing. Rather, it would seem that other conditions than the nature of the food supply determined the slow progress and final arrival of the higher mammals.

Mesozoic mammals were probably more or less omnivorous, with a penchant for the eggs of reptiles and birds. This may have played an important part in the downfall of the dinosaurs and other terrestrial reptiles who were presumably accustomed to depositing their eggs on the warm sands and leaving them unattended to be incubated by the heat of the sun. In any event, the fossil remains of land reptiles are mingled with ever increasing numbers of mammal jaws and teeth in successively higher strata deposited toward the close of Mesozoic time. Then came an abrupt change, a veritable revolution, affecting all the vertebrate population of the earth. The close of the Mesozoic Era is marked by the complete downfall of the reptiles and was soon followed by the advent in great force of the placental mammals. This overthrow of reptile domination cannot, however, be attributed to success on the part of placental mammals in a contest for supremacy with the saurians. Our records indicate that it was not until after the dominant reptiles had disappeared that the placental mammals appeared upon the scenes. If the downfall of the reptiles is to be attributed to the achievement of the mammals, all credit for that successful revolution must be given to the non-placental mammals of the Mesozoic Era. More likely, mammalian depredations constituted only a very minor part of the many factors involved in this significant change.

The close of Mesozoic time was marked by far-reaching physiographic changes which involved the uplift of continents and the crumpling of strata into vast mountain ranges as well as the initiation of volcanic outbursts on an unusually vast scale. The resulting climatic changes are not known with such fullness as characterizes our knowledge of late Paleozoic climates. There may not have been so sharp a zonal concentration of tropical warmth and polar coolness as today. Yet there is some evidence which indicates that about this time, glaciers were active in British Columbia and Colorado. These may have been in high mountains or on lofty plateaus rather than close to sea level, but nevertheless their presence is significant. In all probability the crustal movements which marked the close of Mesozoic time, like those which closed the Paleozoic Era, were accompanied by marked refrigeration of the earth's atmosphere. By this time the reptiles had passed through their racial maturity and were in racial old age with all that such senility implies. Peculiarly adapted for special environments and special climates, they were unable to change their bodily structures to conform to the needs of new surroundings. Extinction of the dinosaurs, the pterosaurs, the plesiosaurs, and the icthyosaurs was the inevitable result of changing geologic factors. Upon the stage thus vacated the placental mammals promptly appeared and with the opening of the Cenozoic Era they became the dominant type of terrestrial life.

GEOLOGIC FACTORS IN THE EVOLUTION OF TERRESTRIAL MAMMALS.

The evolution of placental mammals upon the various land areas of the several continents gives to the Cenozoic Era the designation, "Age of Mammals." Diversified climates, varied physiographic conditions, and more or less complete subdivision of lands into isolated provinces, all contributed to the wide and rapid development of the higher mammals. Matthew* has assembled a multitude of pertinent facts in his study of the influence of climate upon the dispersal of mammals during this time. Numerous authors have called attention to the obvious influences of environment upon mammalian progress. One illustration will suffice to bring the general principles clearly to mind.

The progressive development of the horse family from the little, four-toed, generalized, ancestral type to the highly

* W. D. Matthew, Climate and Evolution; Annals New York Acad. Sci., Vol. 24, pp. 171-318, 1915.

specialized horse, rhinoceros, and tapir of today is one of the stock illustrations of the evolutionist. The evolution of the horse is clearly in the line of special adaptation to a peculiar environment. The foot has been made more and more efficient for locomotion over a smooth, regular, and rather hard surface, although the changes directed toward that end have made it less capable of travelling over loose ground and of little use for striking or grasping or any other of the varied processes for which the feet of many-toed animals are used. The increased length in the lower leg and foot have increased the length of stride without decreasing its quickness. The reduction and disappearance of the side toes and the concentration of the step on the single central toe serve to increase the speed over smooth ground. These changes in the limbs and feet made it necessary for the grazing animal to have a longer head and neck so that the mouth was enabled to reach the ground. At the same time, the record shows a change in the teeth, which have progressed from short-crowned to long-crowned. Thus the animal has been enabled to subsist on the hard, comparatively innutritious grasses of the dry plains, which require much more thorough mastication than do the softer green foods of the swamps and forests. "All these changes in the evolution of the horse are adaptations to a life in a region of level, smooth, and open grassy plains such as are now its natural habitat. At first the race was better fitted for a forest life, but it has become more and more completely adapted to live and compete with its enemies or rivals under the conditions which prevail in the high, dry plains of the interior of the great continents."*

So complete is the array of fossil specimens which show the various steps in this particular progressive development and so striking is the evidence that successively more equine animals lived in successively more recent time, that there is a strong tendency to interpret the history of the horse in terms of a certain kind of orthogenesis. The interpretation of some is represented by the frivolous little verse which finds its place in every paleontologist's anthology:

"Little Eohippus was no bigger than a fox,
And on four toes he scampered over Tertiary rocks.
'But,' said little Eohippus, 'I am going to be a horse,
And on my middle fingernails to run my earthly course.' "

* W. D. Matthew, Evolution of the Horse; American Museum, Nat. Hist., Guide Leaflet No. 36, p. 29, 1913.

Recalling the progressive development of many organic phyla, which seem to have moved directly toward a modern type, it is very easy for us to assume that the earlier members of the phylum were possessed of impulses directing them toward the attainment of a definite though distant goal.

As a matter of fact, of course, little Eohippus had no information concerning the characteristics of the noble steed which was to be his Pleistocene descendant. His highest ambitions were presumably to escape from the stealthy approach of an ancestral feline and secure for himself safe pastures on the western prairies. To understand the straightforward progress of the odd-toed, hoofed mammals, culminating in the modern horse, one must know the changing environment which accompanied the organic modifications. During the Age of Mammals, that portion of North America which we call today the Great Plains was undergoing a radical alteration. In early Tertiary time that region was low and moist, with many swamps and widespread forests. Apparently the cordilleran barrier between it and the moisture-laden winds of the Pacific was much lower than it is today. The physical record during Tertiary time is marked by a progressive desiccation and cooling of that area. This may have been in large part a response to the building of mountain barriers at the west, although it was undoubtedly due in considerable degree to changes in the earth's atmosphere which were bringing about a more pronounced zonal distribution of temperature. Whatever may have been the causes, it is clear that the evolution of the horse family paralleled an environmental change from forested lowlands to grassy prairies and treeless savannas. This seems to have been the directing influence. Each improvement of the ancestral horses in strength and efficiency of limb, in perfection of hoof, and in effectiveness of grinding teeth, seems to have been a response to demands made by the changing environment. The four-toed, and many of the three-toed, horses were forest dwellers accustomed to browsing rather than grazing, living on the soft, springy forest mold rather than the hard, unyielding turf of the prairies. The gradual diminution of the area of forests and the expansion of the prairies not only gave the opportunity but directed and impelled the achievement of the modern type of horse. Orthogenesis seems to be a response to progressive changes in environment rather than to definite ambitions with which a creature may be endowed.

GEOLOGIC FACTORS IN THE EVOLUTION OF MAN.

Although the main outlines of the story of man's origin through modification from an arboreal anthropoid ancestor are well known, many of the details of interest in this connection await discovery. Many students of this problem have inferred that south-central Asia was the region in which this development took place, but the inference is based as much on lack of knowledge as upon deductions from known facts. One must confess that Hrdlicka's contention that east-central Europe may have been the birthplace of mankind is well within the bounds of possibility. Regardless of our lack of knowledge concerning the locality, there is no doubt but that the ancestry of man is traceable through a strain of anthropoids which gradually changed their habits from those associated with life in trees to those made necessary by life on the ground. Barrell* has sketched an interesting picture of environmental changes in south-central Asia which he believes directed that modification of the "ape-man." Gradual desiccation and increasing cold are supposed to have caused a progressive dwindling of the forest areas north of the Himalaya Mountains. The treeless steppes of the northland expanded southward, and encroached more and more upon the wooded regions. Retreat toward the south was supposedly cut off by the new-formed barrier of the impassible mountain range, and necessity forced upon the arboreal anthropoids their modification to terrestrial life. It is fairly well established that the record of man's ancestry must have included some such modifications of habits and body structures, and these are much more likely to have been imposed upon the creatures by the external compulsion of environmental changes than to have been a response to ambitions innate within the anthropoid breast.

Every section of human history bears the unmistakable stamp of the geographic environment in which man progressed from primitive barbarism to the complex civilization of today. Geologic factors are the warp without which the tapestry of human progress could never have been woven. A single illustration will serve to suggest the close relationship between man and his environment. Miss Semple has called attention

* J. Barrell, Probable Relations of Climatic Change to the Origin of the Tertiary Ape-man, Scientific Monthly, Vol. 4, pp. 16–26, 1917.

to the intimate relations which exist between marine highways and the later stages of human culture. "The progress of history has been attended by an advance from smaller to larger marine areas, with a constant increase in those manifold relations between peoples and lands which the water is able to establish. Every great epoch of history has had its own sea, and every succeeding epoch has enlarged its maritime field. The Greek had the Aegean, the Roman the whole Mediterranean, to which the Middle Ages made an addition in the North Sea and Baltic. The modern period has had the Atlantic, and the twentieth century is now entering upon the final epoch of the World Ocean."*

The Caucasian race, reaching the shores of the inclosed or marginal seas which form the eastern Mediterranean, found there the nursery in which were taken the first feeble steps toward the conquest of the water. Success in that limited environment was followed by the opportunity to pass into the kindergarten of the open Mediterranean. With sharpened wits and strong hearts resulting from the lessons learned in that kindergarten, the white races were ready a little later to embark along the shores of the eastern Atlantic, and in the training school afforded by its embayments, coastwise navigation was perfected. Ere long, intrepid navigators matriculated in the college of the open Atlantic; and today their successors pursue post-graduate courses in the University of the World Ocean. Again, the story of life development is phrased in terms of capable individuals presented with opportunities inherent in particular environments. Had the outlines of all the continents been like those of Africa, one can but wonder if giant ocean liners would have been a product of the twentieth century or whether they must have awaited some far distant future time.

Any broad survey of the strain of life development leading to man as we know him today can not fail but impress us with the unique succession of felicitous events which in the last analysis are dependent upon the internal conditions and external relations of the earth itself. Progress from simple to complex, from lowly organisms to higher types, from primitive conditions to "better things," is by no means a necessary consequence of

* E. C. Semple, Influences of Geographic Environment, New York, 1911, p. 311.

life. The ceaseless urge within the living creature appears to be only an impetus making for change. Variation may be in any direction, for better or for worse. Environment and environmental changes seem to be the directive influences. It is hardly to be expected that another planet, even among the myriad planets which may pertain to the stellar galaxy, should have had a geologic history sufficiently similar to that of our earth to have developed life along similar channels. Although there is no apparent reason for assuming that life as we know it represents the only possible manifestation of the great mysterious vital forces inherent in the spiritual universe, here is a strong argument that man is actually unique both in time and space. The law of probabilities almost excludes the possibility that anywhere else or at any other time vital energy has manifested itself in protoplasm and that protoplasm has been led through the long chain of upward progress to a creature which would be even an approximate duplicate of mankind.

If geologic factors have thus directed the history of life development and thus in a very real sense are responsible for the coming of mankind, there is no escape from the conclusion that the future history of man will likewise be under the sway of environmental factors. The key supplied by knowledge of the past is the only key available with which to unlock the door of the future. Man, a product of environment, may boast about the success with which he has subdued the earth, but the quiet power of the constantly operative geologic factors continues to define the limits within which his future activities must be set. The geologist has reason to be very optimistic concerning the possible span of the future existence of the earth as an abode for life. "While there is to be, with little doubt, an end of the earth as a planet, and while perhaps previous to that end conditions inhospitable to life may be reached, the forecast of these contingencies places the event in the indeterminate future. The geologic analogies give fair ground for anticipating conditions congenial to life for millions and tens of millions of years to come."*

Man, so far as we can tell, is unique among all animals in the possession of a definite moral purpose, a purpose to utilize to the fullest his potential ability for the "higher good." That

* T. C. Chamberlin, A Geologic Forecast of the Future Opportunities of Our Race; Science, Vol. 30, pp. 937-949, 1909.

higher good in its ultimate materialistic aspect means simply the continued occupation of the earth by humankind for as long a period of time as possible. With such thoughts in mind it is obviously well worth while to inquire into the place in which we find ourselves in the year 1924 when viewed in the long perspective of the whole existence of man as an animal species set in a peculiar if not unique geographic environment.

Homo sapiens is still a youthful species. His present span of life is measurable by some such figure as forty thousand years. The total span of existence of the individual species of air-breathing vertebrates has probably averaged three or four hundred thousand years. Our knowledge of the antiquity of many existing species of vertebrates indicates that among the present population of the lands, man is distinctly a newcomer. He has not yet lost the plasticity and virility of youth. He is still in the adolescence of the species and has not yet settled down into the conservatism and inflexibility of racial maturity.

The youthful species has been passing through a stage of provincial development and is even today embarking upon a more cosmopolitan career. The spread of mankind over the habitable globe has placed different individuals in diverse and isolated environments. Each continent has developed its own racial varieties. Each geographic region has witnessed the evolution of racial subdivisions having each its own distinctive characteristics. The differentiation of mankind into scores of ethnic strains has doubtless been directed in no unmistakable degree by the diversity of environmental conditions which man has found in the progressive peopling of the lands. But the last three centuries have witnessed the breaking down of barriers. Mountain and sea, forest and desert no longer serve to separate human provinces. Distance has been annihilated; barriers have been surmounted; isolation is today well nigh impossible.

Man has utilized his best ingenuity and greatest strength in an attempt to mold his geographic environment toward a uniform type. Deserts are irrigated; swamps are drained; forests are cut down; scattered clumps of trees are carefully planted and nurtured on wind-swept savannas. As a geographical agent, man works consciously toward uniformity. The world is fast becoming a neighborhood. In consequence, differentiation is waning almost or quite to disappearance.

Racial fusion or assimilation is now taking the lead. The provincial types are mingling and modifying into the cosmospolitan. For man, as for every other creature, that transition from provincial to cosmopolitan types is a time of appraisement and testing. The products of the varied provinces are now balanced against each other. The least fit must inevitably be submerged, while the more efficient and better qualified contribute largely to the final product.

But that does not mean that the most selfish, most powerful, most numerous, or even the most clever of the varied human types, from which selection is even now being made, will be the type for cosmopolitan humankind. The strain that leads to man has been clearly characterized by an increasing breadth and depth and strength of the cooperative spirit. Back at the dawn of human history, when our anthropoid forefathers maintained a most precarious existence among carnivorous mammals, to whose depredations they were exposed more and more frequently as the comparatively safe haven of the forests disappeared from the expanding prairies, the necessity of cooperation for attack and for defense was ingrained in every human survivor. The social history of man is marked by constant increase in the unit within which cooperation is workable. Family life has been submerged within that of the clan; clans were associated into tribes; tribes, into nations; nations, into alliances and leagues. Note how the geologic factors impose upon the future progress of mankind far greater and more intelligent cooperation than has yet been attempted.

Human development has thus far been marked by expansional evolution. There have always been vacant lands available for settlement, when the constant press of growing population made necessary the expansion of a community by migration or colonization. Only in times of war or in such communities as the densely populated valleys of India or China has mankind in large units ever faced the absolute necessity of conserving with utmost frugality all available food supplies. It is perfectly possible today, as it has always been in the past, for mankind to secure an abundance of food for every member of the human family. All that is required is a reasonable amount of industry and an intelligent distribution of products. But this period of expansional evolution cannot continue many centuries longer. For man, as for Paleozoic invertebrates, the tide must turn. Expansional evolution will give way to restrictional development. Exactly how many billion human souls may find sustenance upon our earth no one can accurately estimate, but that there is a limit to the possibilities of the earth as an abode for human beings, no careful thinker who does not blink at facts can possibly deny. The limit may be as low as four billions, or as many as ten, but somewhere there is a deadline.

Far back at the very beginning of life development upon our earth, man's remote Protozoan ancestor sacrificed the ability to utilize the energy of the sunlight and make food for itself from inorganic compounds. That sacrifice bore rich fruit in the deployment and perfecting of animals of all sorts. Not the least of its consequences is just now being impressed upon mankind in the compulsion toward cooperation. Dependent upon other organisms, in the last analysis, plants, for sustenance, the future generations must conserve all available food supplies and develop to the utmost a thoroughly reliable and adequate network of transportation facilities. Mutual interdependence will become more and more apparent as the total population approaches more and more closely its ultimate limits.

How many generations will elapse before the present sixteen hundred million people on the earth have multiplied until the population reaches its absolute maximum, no one can tell. Decreasing death rates and decreasing birth rates can scarcely be balanced accurately one against another. The conquest of the tropics is well begun, but the conquest of polar lands has only recently been suggested. Very possibly, amelioration of climate with increasing chronologic distance from the last ice age may appreciably expand the areas available to serve as man's domain. Even within a few hundred years, considerable changes in the earth's atmosphere, due to man's activity in this industrial age, may react favorably by causing further diminution of arctic and antarctic ice fields. Turning from the long perspective of the many tens of thousands of years since the Cro-Magnon race of *Homo sapiens* lived in southern Europe, the few centuries which remain before the earth will have been completely populated by mankind seem to the geologist extremely short.

From the geologic point of view, therefore, the next great crisis in life development is even now imminent, relentlessly forced upon us by geologic factors. The success with which living creatures have weathered every such crisis in the past is fair ground for optimism that this crisis of tomorrow will likewise be successfully negotiated. As in the past, so in the future, success comes because a minority respond to the challenge flung by environmental factors. The pioneers of progress have invariably been a hardy, risk-taking group, endowed with specific virtues which gradually make their way against an overburden of opposition.

Survival values in the past have generally been measured in terms of physical adaptation; survival values in this coming crisis will apparently be psychical rather than physical. Man is unique among animals in several ways, not the least important of which is the fact that he has specialized not along the line of adaptation to any one environment, but along the line of adaptability to all environments. His physical adaptability almost rules out of consideration the physical factors as determiners of survival value. Apparently, therefore, the qualities which will determine man's ability to negotiate successfully this next great crisis in life development will be psychical—mental, moral, and spiritual. Willingness to cooperate with his fellows, coupled with intelligence in devising cooperative ways and means, will be the measure of man's fitness individually and collectively to survive.

CONCLUSION.

The geologist, fresh from his survey of geologic factors in life development, has every reason to take an optimistic outlook for the future of mankind. As the twig is bent, so the tree is inclined. Geologic factors in the past have directed life onward and upward to its present high plane. A physical organism has been perfected to such a degree that it possesses a knowledge of moral law, a sense of rightness, a confidence that its reasoning mind finds response in a rational universe, and a hope that its spiritual aspirations will find increasing answer in a spiritual universe. Intelligent enough to read the record of the past and face the problems of the present, it is inconceivable that man should fail as he attempts to develop within himself a spirit of cooperative endeavor strong enough and intelligent enough to insure his success in the critical moments of the future.